SCIENCE.

The Power of Movement in Plants. By Charles Darwin, LL.D., F.R.S. Assisted by Francis Darwin. With Illustrations. (Murray.)

The sum and substance of this book, which, like all of Mr. Darwin's, contains a great mass of facts and generalisations, is *circumnutation*; all the various movements of different parts of plants being modifications of that phenomenon. This word stands for a circularly bowing motion of an organ, by which it describes irregular ellipses, loops, or zigzags, as it is successively directed towards all points of the compass. The cause is an increased turgescence on the convex side of the organ, which precedes growth, and which is then followed by a similar turgescence on the other side. If there be a *pulvinus*, which consists of an aggregation of small cells arrested in their development, then the increased turgescence of the cells on opposite sides is not followed by growth, and the organ can consequently circumnutate for much longer periods. "On the whole," Mr. Darwin says, "we may at present conclude that increased growth, first on one side and then on another, is a secondary effect, and that the increased turgescence of the cells, together with the extensibility of their walls, is the primary cause of the movement of circumnutation" (pp. 2, 3).

The work contains mines of wealth of observations on circumnutation, based on the most minute and careful experiments upon the movements of radicles, "hypocotyls" and "epicotyls" of seedlings; also upon flower-stems, stolons, and leaves; the "hypnotropic" or sleeping states of leaves being also brought about by modified circumnutation. The motions of climbing plants, and the influences of light, gravity, and other *stimuli*, are fully discussed in their bearings upon the subject.

Commencing with radicles, we learn that, as soon as the tip has protruded from a seed, it begins to circumnutate, the use apparently being to aid it in penetrating the soil, by guiding it along the lines of least resistance, and especially into cracks, worm-burrows, &c. Mr. Darwin observes that "geotropism," which is a weak force, does not give a radicle sufficient power to penetrate the ground, but merely tells it which course to pursue. The actual penetration is due to the forces of longitudinal and transverse growth. An ingenious contrivance for growing radicles in circular holes cut in split pieces of wood or in wooden clips connected by a spring showed that the force exerted in the first case, as a transverse strain, was probably more than 8 lbs. 8 oz., and in the latter case 3 lbs. 4 oz.; while the apex increased in length with a force equal to at least a quarter of a pound. I would venture to suggest a possible source of error in the experiment with the pincers, for they only show the least amount of force requisite to open them to a stated distance. There is nothing to show that, if the spring of the clip had been three times greater than it was, the radicle could not have just as easily opened them to the same distance, for it might have possessed, and probably did possess, much greater transverse power; but, *the diameter of the radicle at any point not increasing beyond the requirements of growth*, it could not possibly widen the clips to the full extent of the power possessed. The result of these forces is that the radicle acts like a powerful wedge driven slowly into a crevice and expanding simultaneously.

The author then describes how the arched "hypocotyls" (an abbreviation for "hypocotyledonary axes") and "epicotyls," or developing plumules, rise up and break through the soil by means of their circumnutation, assisted by apogeotropism—that is, as far as the resisting medium will allow of it. The cotyledons are also in constant motion, rising once up and once down in the course of twenty-four hours in a vertical plane. Some cotyledons, like leaves, are provided with a pulvinus, and Mr. Darwin finds that the difference between the movements induced by the aid of pulvini and without such aid is due to the expansion of the cells not being followed by growth in the first case and being so followed in the latter. The tissues of the pulvinus are arrested, and, consequently, the movements of pulvinated cotyledons last much longer than of those without a pulvinus. Cotyledons are affected "paratonically" by light—that is, their daily periodic movements are greatly and quickly disturbed by changes in its intensity or by its absence, showing that their movements are not governed by the actual amount, but by changes in the intensity or degree of light. Mr. Darwin next deals with the sensitiveness of the apex of the radicle to contact of solid bodies or to other irritants. An object which yields with the greatest ease will deflect a radicle. That of a bean encountering the polished surface of extremely thin tin-foil laid on soft sand made no impression on it, but yet was deflected at right angles; while the curvature of the upper part extended for a length of 8 to 10 mm. The results of Mr. Darwin's experiments were that the apex was sensitive to contact, and that an effect was transmitted to the upper part of the radicle, which was thus excited to bend away from the touching object. Sachs discovered that the radicle, a little above the apex, is sensitive, and bends like a tendril *towards* a touching object. But when one side of the *apex* is pressed by any object the growing part bends *away* from the object, and this, Mr. Darwin observes, seems to be a beautiful adaptation for avoiding obstacles in the soil. This, too, appears to be the only known instance of an organ bending away from an object in contact with it.

An exquisite series of experiments was made by affixing cards, thin glass, &c., to the tips of radicles, which consequently curved away towards the opposite side—in some cases to such an extent as to make complete loops or even knots! The motion is affected by different degrees of temperature; and so small a force as the two-hundredth part of a grain sufficed to excite movements in some radicles of the bean. Radicles are also sensitive to prolonged irritation, without any objects being permanently fixed upon them; and, in comparing effects of an irritant with geotropism, the author found that

> "the initial power of an irritant on the apex of the radicle of the bean is less than that of geotropism when acting at right angles, but greater than that of geotropism when acting obliquely on it" (p. 154).

Mr. Darwin found dry caustic to produce similar effects. He also discovered that

> "a thin slice removed by a razor from one side of the conical apex of the radicle causes irritation, like that from an attached object, and induces curvature from the injured surface" (p. 150).

Sachs has shown that pressure at the distance of a few millimètres above the apex causes the radicle to bend, like a tendril, towards the touching object. Mr. Darwin corroborates this, as also another of Sachs' discoveries, that the radicles of many seedling plants bend towards an adjoining damp surface. This peculiar form of sensitiveness resides in their tips, which then transmit some influence to the upper part, causing them to bend towards the source of moisture.

Mr. Darwin next describes the circumnutating movements of the several parts of mature plants. A number were selected from different orders, and especially woody plants, as being less likely to have circumnutating stems, but the result showed that it is a universal phenomenon, the curves described being more or less irregular ellipses, the longer axes of which are directed to different points of the compass, often interrupted by zigzags, triangles, loops, &c. Stolons and runners form no exception, though circumnutating in a very complex manner, being so great in amplitude as to be almost comparable to that of climbing plants. They are thus aided in passing over obstacles, &c.

With leaves Mr. Darwin found it to be so general that he concludes it would not be rash to assume that growing leaves of all plants circumnutate, as is probably the case with cotyledons. The seat of the movement generally lies in the petiole, but sometimes in the blade as well. The periodicity of the movements of leaves is peculiar. They generally rise a little in the evening and the early part of the night, and sink on the following morning. It is determined by the daily alternations of light and darkness.

After having described circumnutation as a general phenomenon of growing organs in the fifth chapter, the author enters upon the field of "modified circumnutation"—that is, where this has become utilised for special purposes. He had previously and elsewhere described the processes of climbing plants, and now only observes that it is an amplified state of circumnutation, probably due to a moderately increased growth spread over a considerable length of the moving organ, preceded by turgescence and acting successively on all sides.

Two chapters are devoted to a full and apparently exhaustive discussion on the sleep or nyctitropic movements of leaves. These consist of the phenomena of an upward or downward movement of leaves and leaflets, of the folding along the mid-rib, of the rotating on the pedicels, &c., the general result being either to protect the upper surfaces by covering them one upon another, by crowding the leaves together, or by placing them vertically. In every case the object is to avoid the evil effects of radiation into the open sky; for Mr. Darwin has proved that leaves compelled to remain horizontally at night suffer much more from radiation than when placed with their edges vertical. One would like to ask the question whether this will account for the phyllodinous species of acacia, as well as the gum-trees, having their foliar organs so often vertical, instead of horizontal, in Australia.

Movements excited by light and gravitation occupy the next four chapters, while the twelfth and last deals with a general summary and concluding remarks.

Heliotropic movements are determined by the direction of light, while periodic movements are effected by changes in its intensity, and not by its direction. Mr. Darwin shows that a heliotropic motion (towards light), apheliotropic (away from light), diaheliotropic (taking up a position transverse to light), and paraheliotropic (avoiding intense light) are all forms of circumnutation; though how the actual causes—themselves not always known—act in producing these effects is unknown at present.

The manner in which organs of plants move towards a lateral light shows that it is evidently the movement of circumnutation which gives rise to or is converted into heliotropism, &c. This view is borne out by the existence of every possible gradation between a straight course towards a lateral light and a course consisting of a series of loops and ellipses. The transmitted effects of light are curious. While observing the accuracy with which the cotyledons of

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LITERATURE.

MR DARWIN'S NEW BOOK.*

Although the farmer and the market gardener have a well-grounded faith that their turnips and cabbages will not walk over the field fence or garden wall, it is nevertheless a matter of common observation that plants do move more or less, and sometimes in very curious fashion. Strange histories may be read in the course of roots, stems, and branches. We are all familiar with the unhappy fate of the aspen, doomed to shiver incurably for ever and aye, though never a breath of wind be discernible to stir its nervous leaves. Most of us have heard of the sensitive plant that in a garden grew, and many of us may have observed with what keen resentment it shrinks from a foreign touch. The poet, who apparently rose betimes, has left it on record how, when Phœbus 'gins arise, then winking marybuds begin to ope their golden eyes. The flowers and leaves that open wide their bosoms to receive the gentle and cheering influences of the sun are observed to close and draw themselves together before the ungenial approach of rough blasts or the coming on of cold and darksome night. The "Jerusalem" artichoke—it has no more to do with Jerusalem than the famous ship Bellerophon has to do with "Billy Ruffian"—is really, as the schoolboy that cons the curiosities of language knows, the "girasol," that is, the "turn-to-the-sun" artichoke; and the lovers of flowers know very well how quickly plants, when removed from a dark room or a shady place, turn their leaves to the light and the warmth of the sun. Since the discovery of Linnæus, plants have been known to sleep, although the knowledge of this fact has perhaps not extended very far beyond the circle of botanists and of observant or imaginative poets; Mr Darwin now draws firm distinctions between the phenomena of real plant-sleep and other very similar phenomena that are really of an essentially different nature. In previous works Mr Darwin has had much to say on the movements of plants. In one work he has fully discussed the inconstant nimbleness of climbing plants, with all the vagaries of creepers and runners and the philosophy of tendrils. In another work he has recorded observations and comments on flesh-eating plants, with all the strange behaviour of special gland hairs and the not unnatural stomachic disturbance of cells in the near prospect of a non-vegetable dinner. The present volume takes a wider sweep. It has for its chief object "to describe and connect together several large classes of movement common to almost all plants." Specimens fairly representing the length and breadth of the vegetable kingdom have been carefully chosen and carefully observed. The vast number of leading observations here detailed form the chief portion of the new volume; the explanations accompanying and the conclusions drawn from the observations occupy but a small space. The labour and attention spent by Mr Darwin and his sons on the experiments recorded here could have been supplied only from the patience of genius and an overmastering constraint to the search after truth. The generalisations that Mr Darwin reaches on the basis of his observations tend decisively to the support and further elucidation of the fitness of the hypothesis that bears the name of the greatest master in biological science.

The most widely prevalent movement, called by Sacks "revolving nutation," is described here under the more convenient name of "circumnutation." It is "essentially of the same nature as that of the stem of a climbing plant, which bends successively to all points of the compass, so that the tip revolves." The description of its character and significance ought to be read in the author's own words.

If we observe a circumnutating stem which happens at the time to be bent, we will say to the north, it will be found gradually to bend more and more easterly, until it faces the east; and so onwards to the south, then to the west, and back again to the north. If the movement had been quite regular, the apex would have described a circle, or rather, as the stem is always growing upwards, a circular spiral. But it generally describes irregular elliptical or oval figures; for the apex, after pointing in any one direction, commonly moves back to the opposite side, not, however, returning along the same line. Afterwards other irregular ellipses or ovals are successively described, with their longer axes directed to different points of the compass. Whilst describing such figures, the apex often travels in a zig-zag line, or makes small subordinate loops or triangles. In the case of leaves the ellipses are generally narrow. . . .

Apparently every growing part of every plant is continually circumnutating, though often on a small scale. Even the stems of seedlings before they have broken through the ground, as well as their buried radicles, circumnutate, as far as the pressure of the surrounding earth permits. In this universally present movement we have the basis or groundwork of the acquirement, according to the requirements of the plant the most diversified movements. Thus, the great sweeps made by the stems of twining plants, and by the tendrils of other climbers, result from a mere increase in the amplitude of the ordinary movement of circumnutation. The position which young leaves and other organs ultimately assume is acquired by the circumnutating movement being increased in some one direction. The leaves of various plants are said to sleep at night, and it will be seen that their blades then assume a vertical position through modified circumnutation in order to protect their upper surfaces from being chilled through radiation. The movements of various organs to or from the light, so general throughout the vegetable kingdom, are all modified forms of circumnutation; as again are the equally prevalent movements of stems, &c., towards the zenith and of roots towards the centre of the earth.

In accordance with these conclusions, a considerable difficulty in the way of evolution is part removed, for it might be asked, how did all their diversified movements for the most different purposes first arise? As the case stands, we know that there is always movement in progress, and its amplitude, or direction, or both have only to be modified for the good of the plant in relation with internal or external stimuli.

The cause of all such bending movements is not altogether clear. It is plain, however, that the old theory of increased growth cannot be maintained as the fundamental cause. In the case of growing plants, increased growth on one side causes a bend towards the other side; the development of tissue goes on more rapidly on the convex side; but it has lately been shown that such increased growth is preceded, at all events in most cases, by a previous swelling on the convex side. And similar movements are present, along with swelling of the cells, where there is no increased growth. In the case of parts provided with a joint or pulvinus, whose cells have ceased to increase from a very early age, we find that the swelling and subsidence of the cells does not result in increased growth, although it is followed by movement. It has further been pointed out that the increased extensibility of the cell-walls is the most important element in the case; and it is obvious that such extensibility must accompany increased turgescence or swelling. After weighing the evidence, Mr Darwin "at present concludes that increased growth, first on one side and then on another, is a secondary effect, and that the increased turgescence of the cells, together with the extensibility of their walls, is the primary cause of the movement of circumnutation." But "why every part of a plant whilst it is growing, and in some cases after growth has ceased, should have its cells rendered more turgescent and its cell-walls more extensile first on one side and then on another, thus inducing circumnutation, is not known. It would appear as if the changes in the cells required periods of rest." And various other suggestions are dropped incidentally throughout the work.

The paramount importance of circumnutation in the life of every plant, is sufficiently insisted on; and it is shown in detail how certain important classes of movement arise from modifications of the general principle. These classes of movement consist of those due to greater longitudinal growth along the upper than along the lower side of a part, which is thus caused to bend downwards, and to the reversed process, in consequence of which the part bends upwards; the movements proper to climbing plants, commonly called revolving nutation; the nyctitropic (night-turning) or sleep movements of leaves and cotyledons; and the two immense classes of movements excited by light and gravitation.

When we speak of modified circumnutation we mean that light, or the alternations of light and darkness, gravitation, slight pressure or other irritants, and certain innate or constitutional states of the plant, do not directly cause the movement; they merely lead to a temporary increase or diminution of those spontaneous changes in the turgescence of the cells which are already in progress. In what manner, light, gravitation, &c., act on the cells is not known; and we will here only remark that, if any stimulus affected the cells in such a manner as to cause some slight tendency in the affected part to bend in a beneficial manner, this tendency might easily be increased through the preservation of the more sensitive individuals. But if such bending were injurious, the tendency would be eliminated unless it was overpoweringly strong; for we know how commonly all characters in all organisms vary. Nor can we see any reason to doubt that after the complete elimination of a tendency to bend in some one direction under a certain stimulus, the power to bend in a directly opposite direction might gradually be acquired through natural selection.

Numerous as are the movements ascribed to the agency of modified circumnutation, "there are others which appear to have had a quite independent origin; but they do not form such large and important classes." Mr Darwin gives examples, and points out the marks of difference. "Yet the difference between the two sets of cases may not be so great as it at first appears."

We have not entered into explanations of the arduous and ingenious devices whereby Mr Darwin and his son compelled their plants to reveal the secret of their movements. For these we must refer to the book itself. The results of the observations are not merely stated in words, but there are some two hundred illustrations, most of which trace the course of movement of the various plants under various conditions. The experiments are of inexhaustible interest, and while they fill one with utter admiration, they irresistibly testify to the power and delicacy and alertness of the author's mind, and an indefatigable perseverance that is nothing short of marvellous. We conclude with the author's summary of a most important, though really distinct, part of the investigations included in this volume; we refer to the wonderful quasi-nerve functions of the tip of the radicle.

Finally, it is impossible not to be struck with the resemblance between the foregoing movements of plants, and many of the actions performed unconsciously by the lower animals. With plants an astonishingly small stimulus suffices; and even with allied plants one may be highly sensitive to the slightest continued pressure, and another highly sensitive to a slight momentary touch. The habit of moving at certain periods is inherited both by plants and animals; and several other points of similitude have been specified. But the most striking resemblance is the localisation of their sensitiveness; and the transmission of an influence from the excited part to another which consequently moves. Yet plants do not of course possess nerves, or a central nervous system; and we may infer that with animals such structures serve only for the more perfect transmission of impressions, and for the more complete intercommunication of the several parts.

We believe that there is no structure in plants more wonderful, as far as its functions are concerned, than the tip of the radicle. If it be lightly pressed, or burnt, or cut, it transmits an influence to the upper adjoining part, causing it to bend away from the affected side and, what is more surprising, the tip can distinguish between a slightly harder and softer object, by which it is simultaneously pressed on opposite sides. If, however, the radicle is pressed by a similar object a little above the tip, the pressed part does not transmit any influence to the more distant parts, but bends abruptly towards the object. If the tip perceives the air to be moister on one side than on the other, it likewise transmits an influence to the upper adjoining part, which bends towards the source of moisture. When the tip is excited by light (though in the case of radicles this was ascertained in only a single instance), the adjoining part bends from the light; but when excited by gravitation the same part bends toward the centre of gravity. In almost every case we can clearly perceive the final purpose or advantage of the several movements. Two, or perhaps more, of the exciting causes often act simultaneously on the tip, and one conquers the other no doubt in accordance with its importance for the life of the plant. The course pursued by the radicle in penetrating the ground must be determined by the tip; hence it has acquired such diverse kinds of sensitiveness. It is hardly an exaggeration to say that the tip of the radicle thus endowed, and having the power of directing the movements of the adjoining parts, acts like the brain of one of the lower animals; the brain being seated within the anterior end of the body, receiving impressions from the sense-organs, and directing the several movements.

The closer *rapprochement* of vegetable and animal physiology is advanced a distinct and very large stage by the publication of the present work.

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* THE POWER OF MOVEMENT IN PLANTS. By Charles Darwin, LL.D., F.R.S., assisted by Francis Darwin. With Illustrations. London: John Murray. 1880.